# Hurricane Andrew's Impact on Freshwater Resources

*Water quality, so important to defining the Everglades' unique ecological composition, appears little affected*

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Freshwater aquatic habitats dominate the landscape of Everglades National Park and southern Big Cypress National Preserve. This article focuses on these freshwater environments to assess Hurricane Andrew's immediate effects on surface water hydrology and water quality, fish and macroinvertebrate communities, and select wildlife species. Much of our short-term assessment relied on a resampling of long-term study and monitoring sites and on systematic aerial surveys. This ten-day assessment is not adequate to determine even the short-term impact comprehensively or to investigate delayed responses by biotic ecosystem components or system recovery dynamics. However, it has effectively illustrated gaps in long-term data sets that limit interpretation of the role of hurricanes, and perhaps other episodic perturbations (e.g., fire, freezes, and drought), in defining the processes and functions that characterize the freshwater environments of the Everglades ecosystem.

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**Hurricane Andrew altered habitat use by fish and crustaceans, reduced alligator reproductive success, and damaged wading-bird roosts and rookeries**

## The Everglades freshwater landscape

A continuum of hydroperiods (the annual duration of inundation) defines several major marsh communities, creating a dynamic mosaic. Sawgrass (*Cladium jamaicense*) prairies, characterizing up to 70% of the Everglades freshwater marsh complex (Loveless 1959), typically occupy short hydroperiod conditions (inundated 6–10 months annually). The wet prairies, with a somewhat longer hydroperiod (inundated perhaps for 6 to 10 months annually), are dominated by beak rush (*Rhynchospora tracyi*), spikerush (*Eleocharis cellulosa*), maidencane (*Panicum hemitomon*), and other emergent aquatics.

Sloughs, which are inundated year-round except during drought conditions, are at the extreme end of the hydroperiod gradient. They are dominated by bladderworts (*Utricularia* spp.), water lilies (e.g., *Nymphaea odorata*), and spatterdock (e.g., *Nuphar luteum*). Sloughs (e.g., Shark River Slough and Taylor Slough) and associated ponds and alligator holes are recognized as exceptionally important wildlife habitat during the dry season and especially during drought periods (SFWMD 1992). Periphyton, an algal mat community generally associated with sloughs, is one of the more conspicuous and ecologically important components of the Everglades system (Rader and Richardson 1992, SFWMD 1992).

## Hydrological response to the hurricane

The Everglades ecosystem is characterized by high water levels during the wet season (May to October, months which have intense, short-duration thundershowers) and low water levels during the dry season (November to April, which have occasional rainfall associated with passage of cold fronts). Over the past century, this conceptually simple pattern has been greatly altered by an elaborate water management network of canals and levees, extending from Lake Okeechobee southward (Figure 1) that has been built primarily to provide for agricultural and urban development. Interpretation of the hurricane's effects on Everglades hydrology and water quality requires an understanding of this altered water-management network.

Today, water enters Everglades National Park from rainfall or as flow from water conservation areas to the north (labeled S-12 structures in Figure 1) and from numerous canals east of the park boundary. Operation of this water-management system results in hydrologic regimes in the park that are typically not consistent with, and less predictable than, the natural seasonal pattern. This altered hydrology has been related to changes in Everglades plant communities and their use by fauna (Loftus et al. 1990, SFWMD 1992). Efforts are under way to restore natural hydrologic conditions in Everglades National Park. Congressionally mandated experiments are developing schedules aimed at reestablishing historic amounts and seasonal timing of water delivery across park boundaries, principally at Shark River Slough and Taylor Slough (Figure 1).

Hurricane Andrew produced relatively little rainfall over South Florida. Although winds damaged 80% of the Everglades National Park hydrologic monitoring equipment, two surviving rain gauges recorded totals of only 4.4 cm and 5.8 cm on 24 August 1992. These values, which are admittedly conservative because of high-wind effects on rain gauges, are not unusual for this region, where localized rainfall in excess of 12 cm/day is not unusual.

Water levels in Everglades National Park increased slightly in response to the hurricane's rainfall and prior and subsequent water-management operations. As illustrated by hydrographs (Figure 2), pre-storm water levels in the park were above average for the summer wet season, as were levels over most of Central and South Florida. Before the storm, water levels in the water-conservation areas north of the park were high, and all 24 gates of the S-12 structures were fully open in an attempt to lower water levels. These large releases into the park started the first week in July and continued well past the storm.

Passage of the storm produced a short-duration wind-driven pulse in water levels of approximately 30 cm (Figure 2). The post-storm rise in water levels reflected the continued high releases through water-control structures at the park boundary after abnormally high post-storm rainfall in the basin to the north. Although the storm did substantial damage to the monitoring network, the absence of a storm surge in the interior Everglades—and the lack of unusually high rainfall associated with the storm—minimized the hydrologic impact of Hurricane Andrew on Everglades National Park and Big Cypress National Preserve.

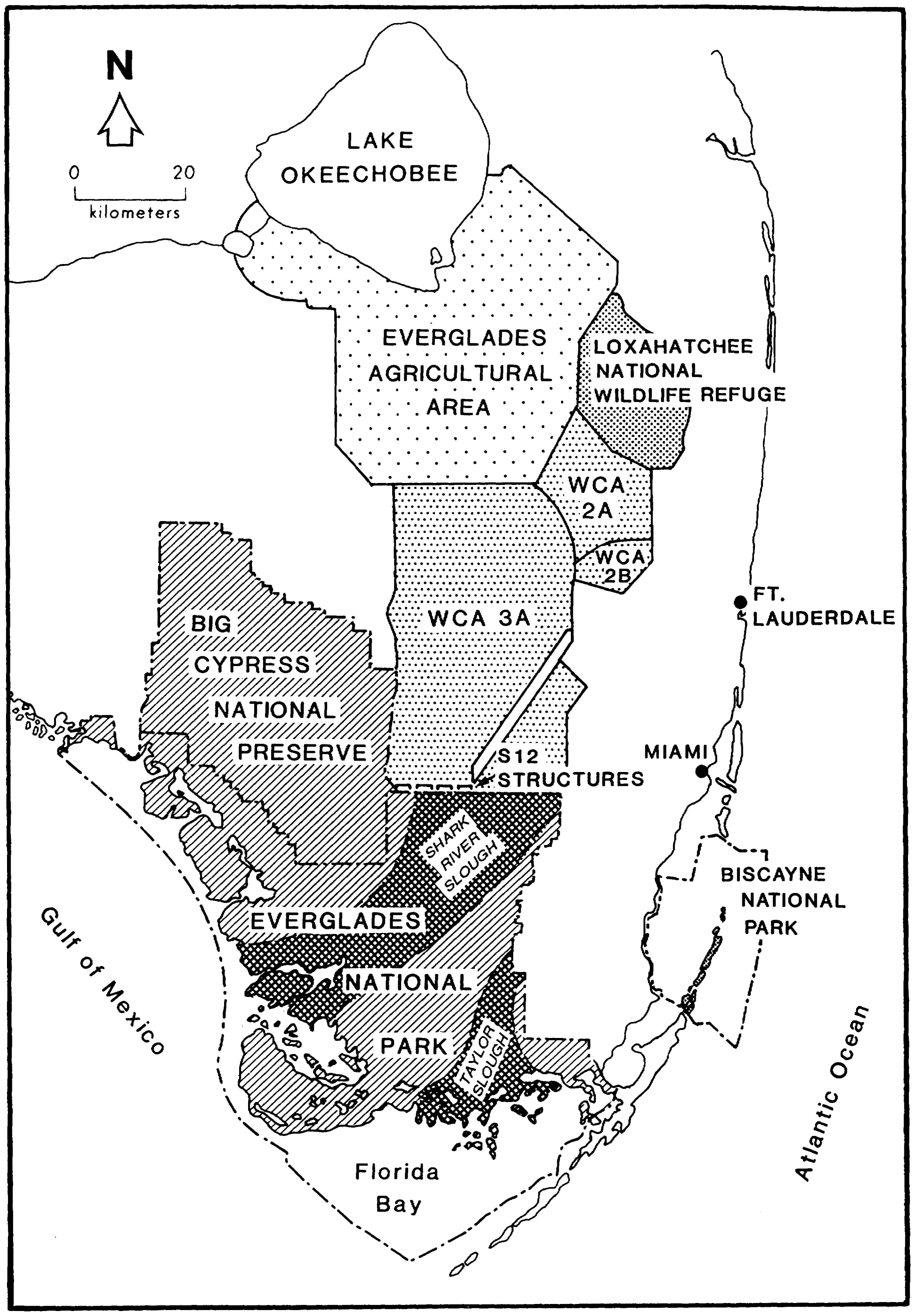


**Figure 1.** Regional location of Everglades National Park and Big Cypress National Preserve, showing their relationship to the water conservation areas (WCA) and, to the north, the Everglades Agricultural Area. The S12 structures are water-management gates.

## Water-quality responses to the hurricane

Oligotrophic, nutrient-poor waters are characteristic of the interior portion of Everglades National Park.

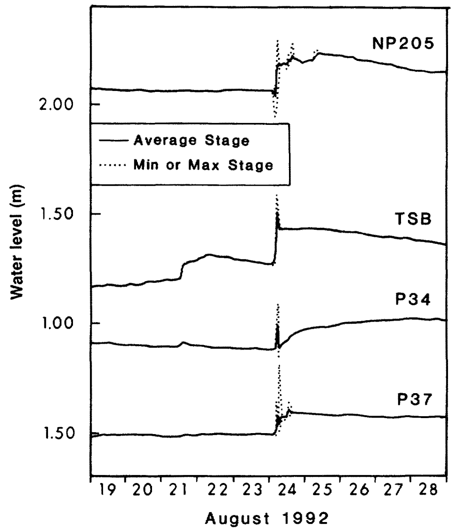


**Figure 2.** Minimal, average, and maximal water levels for selected gauges in Everglades National Park that functioned throughout the hurricane, which hit on 24 August. In the absence of storms, the minimal and maximal levels do not differ measurably from the average. The location of these gauges is indicated in Figure 3.

Soluble reactive phosphorus is typically at or below 4 μg/l in this part of the Everglades (SFWMD 1992). Here, sawgrass is ubiquitous, presumably because it is favored by the low-nutrient environment (Stewart and Ornes 1975). In fact, Davis (1991) and Urban et al. (1993) have suggested that increased nutrient levels, particularly phosphorus, coupled with hydroperiod alteration in the northern water-conservation areas caused vegetation shifts from sawgrass to the more nutrient-tolerant cattail (*Typha*). Similarly, recent reviews suggest that nutrient enrichment shifts species composition and biomass of the periphyton community (Rader and Richardson 1992, SFWMD 1992).

Because Everglades aquatic communities have evolved under oligotrophic conditions and because the system is sensitive to nutrient enrichment, we considered it paramount to evaluate water quality after the hurricane. Our assessment of short-term effects of Hurricane Andrew on surface-water quality included two post-storm data collections (28 August and 17 September 1992) compared with a seven-year historical database of near-monthly sampling at interior stations.

In general, the water-quality database, both before and after the hurricane, reflects a pristine wetlands environment limited by phosphorus availability (Table 1). Hurricane Andrew appeared to have minimal impact on water quality within Everglades National Park. When compared with historical means and interquartile ranges, almost all of the post-storm parameters were within the range of values recorded between 1986 and July 1992. The color of the water at one site post-storm was darker than observed in the pre-storm historic range (Table 1). That site is near the outflow from water-conservation areas at the park boundary, and these data are in agreement with visual

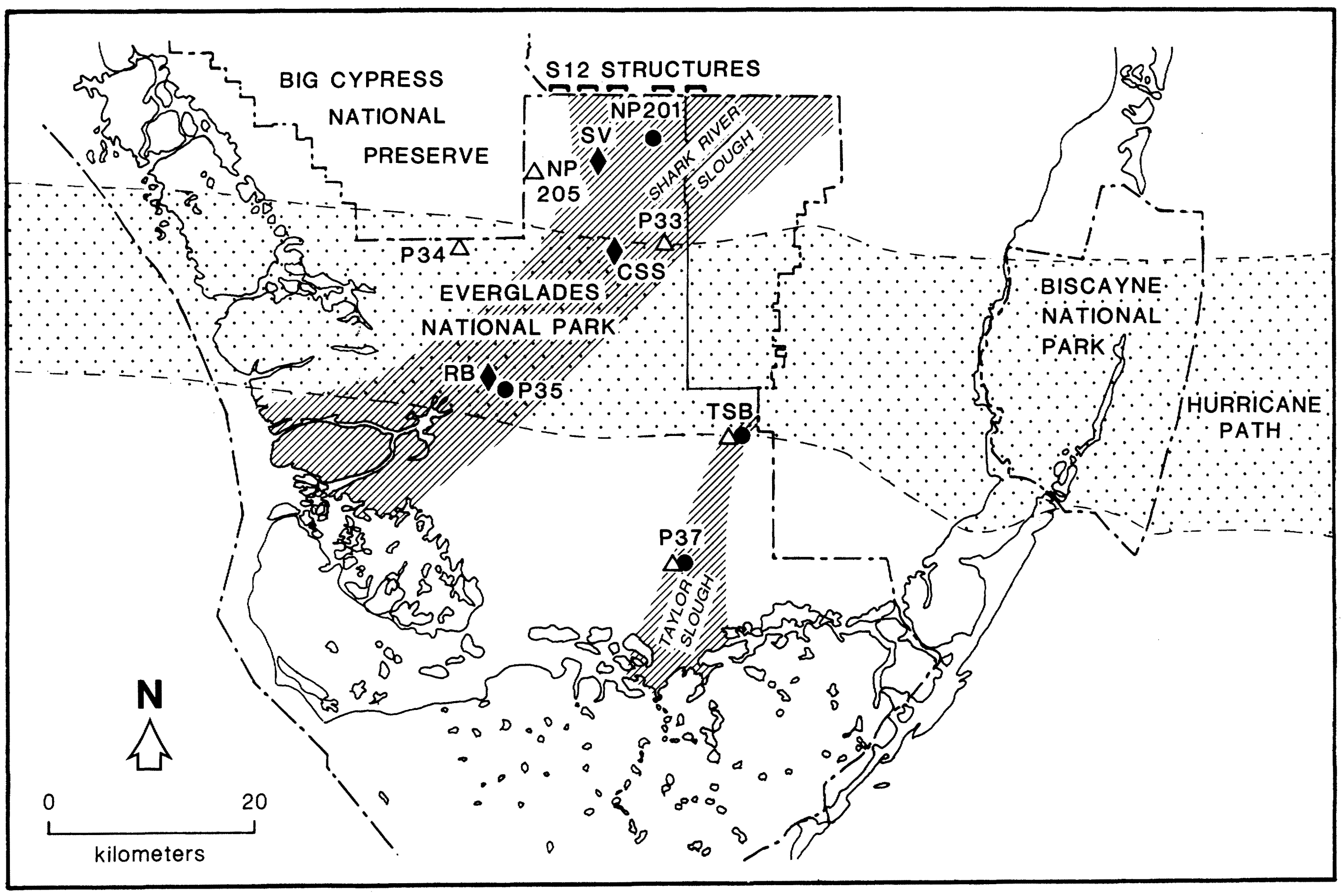


**Figure 3.** Sampling stations in Everglades National Park for pre- and post-storm water quality (filled circles), water-level (triangles), and fish and macroinvertebrate counts (filled diamonds) in long-hydroperiod areas.

**Table 1.** Selected water-quality data—mean, standard deviation, and range of values containing the central 50% of the entire historic data set (interquartile range)—from a seven-year historical database are compared with two post-hurricane samplings. Water temperature, dissolved oxygen, conductivity, total suspended sediments, orthophosphorus, and chloride were also determined, but the post-storm data did not differ significantly from the historical data. All data were collected and analyzed by the South Florida Water Management District.

| Site | | Turbidity (NTU) | Color (platinum-cobalt units) | Ammonia nitrogen (g/l) | Total phosphorus (g/l) |
|---|---|---|---|---|---|
| NP201 | Mean ± SD | 2 ±3 | 37 ± 11 | 61 ± 149 | 8 ± 7 |
| | Range | ND | 17–71 | 10–98 | 4–31 |
| | Interquartile range | 0.8–2.5 | 29–43 | 10–33 | 4–10 |
| | 28 August 1992 | ND | 70 | 10 | 5 |
| | 17 September 1992 | 1 | 51 | 10 | 5 |
| P33 | Mean ± SD | 4 ± 13 | 53 ± 16 | 186 ± 796 | 17 ± 67 |
| | Range | 0–106 | 28–105 | 10–6210 | 4–546 |
| | Interquartile range | 1.1–3.0 | 42–59 | 10–33 | 5–11 |
| | 28 August 1992 | 1 | 55 | 10 | 4 |
| | 17 September 1992 | 2 | 51 | 12 | 4 |
| P35 | Mean ± SD | 3 ± 8 | 68 ± 35 | 69 ± 161 | 19 ± 25 |
| | Range | 0–63 | 26–174 | 10–1070 | 4–137 |
| | Interquartile range | 0.8–2.9 | 41–85 | 10–60 | 6–18 |
| | 28 August 1992 | 0 | 48 | 10 | 4 |
| | 17 September 1992 | 2 | 76 | 10 | 8 |
| P37 | Mean ± SD | 3 ± 3 | 21 ± 15 | 95 ± 172 | 9 ± 12 |
| | Range | 0–18 | 18–91 | 10–820 | 4–74 |
| | Interquartile range | 0.7–3.8 | 15–23 | 10–80 | 4–9 |
| | 28 August 1992 | 0 | 14 | 10 | 4 |
| | 17 September 1992 | 1 | 13 | 10 | 7 |
| TSB | Mean ± SD | 2 ± 2 | 26 ± 16 | 93 ± 149 | 16 ± 22 |
| | Range | 0–11 | 11–131 | 10–640 | 4–133 |
| | Interquartile range | ND | ND | ND | 4–18 |
| | 28 August 1992 | 0 | 26 | 10 | 4 |
| | 17 September 1992 | 1 | 22 | 10 | 7 |

*ND, no data.

observations from helicopter flights suggesting a more intense than normal tannin color in one of the water-conservation areas.

The other sampling sites, more remote from the conservation-area inputs, did not display significantly elevated color values. Similarly, field personnel traveling in the park interior in the days after the hurricane did not report unusually turbid water or water color that suggest algal blooms.

Aside from evaluating nutrient levels in the interior of Everglades National Park, it is important to evaluate the quality of waters entering the park from northern areas. For this assessment, we examined total phosphorus data from four inflow structures to Shark River Slough (S12A, S12B, S12C, S12D; Figure 1). These gates were completely open before the storm, and they remained open during this post-storm assessment. As with the interior sites, post-storm phosphorus concentrations did not differ significantly from pre-storm concentrations.

It appears that Hurricane Andrew had little short-term impact on nutrient levels in the freshwater portion of Everglades National Park (Big Cypress National Preserve lacks long-term sampling stations for comparison). Some limitations in interpreting these data must be mentioned, however. We could have missed immediate impacts during the first three days after the storm (such as increased turbidity or suspended sediments from wind- and wave-induced resuspension).

Moreover, longer-term or delayed impacts may become apparent in future post-storm sampling. It is also possible that for limiting nutrients, such as phosphorus, any temporary increase in water column concentrations could have been rapidly sequestered by physical and biological processes. No measurements of nutrient cycling processes were available for this short-term assessment. Although not conducted in an aquatic ecosystem, post–Hurricane Hugo studies in Puerto Rico rainforests found that the massive pulse of litterfall (i.e., organic input) altered soil and stream nutrient cycling (Lodge et al. 1991). Finally, because of the relatively high lower detection limit of soluble reactive phosphorus (4 μg P/l), an unnoticed pulse of low concentration could have occurred.

## Marsh habitat structure in response to the hurricane

The hurricane's winds piled extensive deposits, or wrack lines, of detached emergent herbaceous vegetation on the windward sides of tree islands. Wrack lines were most evident in central Shark River Slough and the southern end of water conservation area 3A, which are both long-hydroperiod areas. In other portions of Shark River Slough and

Table 2. Comparison of historical and post–Hurricane Andrew data for freshwater fish, prawn, and crayfish density from long-hydroperiod sites. Pre-and posthurricane data were also collected from other sites, but they are not presented here. Plant cover estimates and relative periphyton density are included as habitat descriptors. Plant cover is by visual estimate and relative periphyton abundance was determined by collecting all periphyton material within the 1-square-meter plot and determining wet volume in a graduated cylinder. Numbers are means plus or minus standard deviation, with n = 7 for all parameters listed.

| Site | | | Number /m² | | |
|---|---|---|---|---|---|
| Date | Plant cover (%) | Periphyton (ml) | Fish | Prawn | Crayfish |
| **Central Shark Slough** | | | | | |
| Post-storm | 26 ± 5 | 0 | 1.6 ± 1.5 | 0.7 ± 1.5 | 0.4 ± 0.8 |
| July 1992 | 29 ± 22 | 2171 ± 2274 | 16.3 ± 5.0 | 2.3 ± 2.1 | 2.4 ± 2.1 |
| October 1991 | 7 ± 4 | 4443 ± 1474 | 16.4 ± 5.5 | 17.4 ± 7.4 | 1.7 ± 0.8 |
| July 1991 | 24 ± 16 | 1700 | 7.1 ± 3.7 | 7.6 ± 5.3 | 7.0 ± 4.2 |
| September 1984 | 20 ± 14 | 2183 ± 709 | 46.1 ± 9.4 | 22.3 ± 10.6 | 0.6 ± 0.8 |
| **Rookery Branch** | | | | | |
| Post-storm | 42 ± 14 | 0 | 9.0 ± 4.5 | 3.0 ± 3.3 | 0.1 ± 0.4 |
| September 1985 | 77 ± 12 | 129 ± 197 | 53.6 ± 104.0 | 13.7 ± 3.9 | 1.6 ± 0.8 |
| September 1984 | 55 ± 20 | 266 ± 270 | 58.3 ± 19.2 | 24.4 ± 9.2 | 1.8 ± 1.4 |
| Shark Valley | | | | | |
| Post-storm | 31 ± 11 | 993 ± 430 | 2.7 ± 3.1 | 0 | 0.3 ± 0.8 |
| July 1992 | 15 ± 17 | <200 | 1.7 ± 1.5 | 0 | 0.3 ± 0.8 |
| October 1991 | 8 ± 6 | 3071 ± 3236 | 0.6 ± 0.8 | 0 | 0.7 ± 1.1 |

Taylor Slough, and especially in short-hydroperiod marshes, wrack lines were less evident. Generally, the wrack lines were often thick (approximately 0.75 m), ranged in width from less than 1 m to more than 3 m, and often extended more than 50 m along the edge of tree islands. After Hurricanes Donna in 1960 and Betsy in 1965, Craighead and Gilbert (1962) and Alexander (1967) made similar observations along the windward edges of tree islands and hammocks.

The dense periphyton mat (algae often attached to submerged aquatic plants), as well as the herbaceous vegetation, appeared disrupted by the hurricane. At several locations visited in Central Shark River Slough, the periphyton mat was virtually absent. The physical structure of the periphyton and *Utricularia* mat complex provides essential habitat for aquatic invertebrates and fishes (see Figure 4). There is no pre-storm periphyton mat survey, so we cannot draw any firm conclusions about the geographic extent of mat disturbance.

## Fish and macroinvertebrate responses to the hurricane

We evaluated the immediate effects of Hurricane Andrew on fish and macroinvertebrate relative abundance and spatial distribution. Qualitative surveys by visual observations, electroshocking, seining, and dip netting were conducted at numerous sites, coupled with more detailed quantitative assessments. These assessments included sampling at nine long-term data collection sites.

At each site, we collected seven replicate samples, using a one-square-meter throw trap (see Figure 5) and compared them to pre-storm data (Loftus et al. 1990).[1] Six of these sites were in short-hydroperiod areas and three in long-hydroperiod marshes. In the short-hydroperiod areas, fish and prawn densities are generally lower, whereas crayfish densities are higher (Loftus et al. 1990). The major species collected post-storm were mosquitofish (*Gambusia holbrooki*), sailfin molly (*Poecilia latipinna*), sheepshead minnow (*Cyprinodon variegatus*), sunfishes (*Lepomis* spp.), prawns (freshwater shrimp, *Palaemonetes paludosus*), and crayfish (*Procambarus alleni*).

Because of the year-to-year and seasonal variation in fish and macroinvertebrate abundance in the historical data (Kushlan 1980, Kushlan and Kushlan 1980, Loftus et al. 1990), it is difficult to assess with certainty hurricane impact on aquatic faunal communities. However, the comparison of post-storm with historical quantitative data does reveal some interesting observations (Table 2).

Central Shark Slough, a long-hydroperiod region with several sampling sites, had unexpectedly low densities of fish, prawns and crayfish after the hurricane, compared to historical summer–early fall data. The periphyton-*Utricularia* mat, which had been abundant in previous years and during the routine July 1992 sampling, was absent after Hurricane Andrew. Fishes use the periphyton-*Utricularia* mat complex for foraging and refuge from predation. Therefore, it is not surprising that fish disappeared from this site. Most of the fishes appear to have died or migrated, perhaps temporarily, to more suitable areas. Everglades freshwater fish populations are well adapted to periodic hurricanes, and we expect their abundance to rebound to pre-storm levels when the mat is re-established. Follow-up surveys in the summer of 1993 found that the mat was not re-established and fish density remained low.

The Rookery Branch long-hydroperiod site also lacked periphyton cover after the hurricane and had a decrease in faunal density compared

[1]W. F. Loftus, 1993, unpublished data.

to historical data. This absence of periphyton cover may not have been related to the storm, because observations in past years revealed a limited floating mat. However, this site does illustrate that well-developed periphyton cover enhances habitat quality for fishes and macroinvertebrates. Outside of areas where the periphyton complex and submerged vegetation were depleted, there was little evidence of alteration of the fish fauna (e.g., Shark Valley; Table 2).

There remains some concern about nonnative fishes increasing in abundance post-storm. Loftus (1988) reported that six nonnative fish species have colonized Everglades National Park; these species were introduced mainly by tropical fish hobbyists and by aquaculture activities. After disturbances, such as hurricanes or drought, colonization by nonnative fishes could affect native populations through predation, competition for food resources, and competition for spawning sites (Stauffer 1984). Some nonnative species, such as the Mayan cichlid (*Cichlasoma urophthalmus*) were found to be more abundant at several sites after Hurricane Andrew, but the data that are so far available are insufficient to argue that nonnative fishes have increased in distribution or abundance throughout the area.

Figure 4. Undisturbed periphyton mat located outside the hurricane path. Note the characteristic golden-brown color of the mat and the extremely clear water. Photo: Charles T. Roman.

## Wildlife responses to Hurricane Andrew

The American alligator (*Alligator mississippiensis*) depends almost exclusively on the freshwater habitats of the Everglades landscape. Alligator ponds are the deepest natural habitats in the Everglades freshwater ecosystem. The alligators' activity may serve to maintain these natural depressions. Ecologically, alligator ponds are important refugia for aquatic invertebrates and fish during the dry season, when the wet prairie and sawgrass marshes dry out (Kushlan 1974). These waters, thus, represent concentrated sources of prey for wading birds and other wildlife.

Hurricane Andrew did not appear to affect adult populations of American alligator, but it may have harmed nests, eggs, and hatchlings. Alligator nests, which are mounds of mud and vegetation debris, are constructed in mid-summer (Figure 5). These nests are particularly vulnerable to any flooding by high water (Kushlan 1987) and, undoubtedly, also vulnerable to the high winds of hurricanes.

The National Park Service has monitored alligator nest abundance and nesting success in Shark River Slough since 1985.[2] The monitoring project observed, just one week be-

[2]D. Martin Fleming, 1993, personal communication. South Florida Research Center, Everglades National Park, FL.

fore the hurricane, that 43% of the eggs laid since the start of the 1992 nesting season had been lost to such causes as predation and high water levels. Over the past seven years, egg mortality has averaged approximately 25% in the slough, so even before the hurricane, 1992 was destined to be a poor year.

The post-storm survey revealed that Hurricane Andrew completely destroyed nests containing 27% of 1992's total egg production. The fate of those eggs is unknown because they were hatching as the storm struck. Some may have hatched and the offspring survived; post-storm surveys found some live hatchlings. An additional 8% of the 1992 eggs were lost due to flooding related to elevated post-storm water levels.

Due to uncertainties concerning the fate of damaged nests and eggs, success for 1992 may range from 22% to 49%, well below the average over the past seven years. The effect of this poor year on the long-term reproductive success and population status of alligators in the Everglades system must be closely monitored.

Colonial wading birds are perhaps the most conspicuous wildlife component of Everglades National Park and its vicinity (Bancroft 1989). Hurricane Andrew struck during the wet season when wading bird populations are low, generally at only 10–20% of peak dry-season counts. Fortunately, pre- and post-storm population estimates cover most of the storm path in South Florida (Table 3). The comparison indicates that wading bird populations were little affected, with both pre- and post-storm estimates appearing normal for the wet season. As expected, the white ibis (*Eudocimus albus*) accounted for one half of the total estimated wading bird population.

What was the state of the wading bird rookeries after the storm? There are approximately 160 rookeries in four South Florida counties (Dade, Monroe, Broward, and Collier; Runde et al. 1991). Only 16 were in the hurricane's path and presumably damaged. Nesting activity is low in the summer and fall, so probably many of these sites were unattended; however, severe damage from tree and limb falls occurred in

Figure 5. Investigators sampling for fish, macroinvertebrates, periphyton, and stem density of emergent aquatic plants within the one-square-meter throw trap. Photo: Charles T. Roman.

Figure 6. American alligator nest in Everglades National Park. Photo: William F. Loftus.

the interior rookeries as well as at mangrove sites. At Chicken Key, located in central Biscayne Bay, more than 200 dead wading birds were counted at a roost site. White ibis accounted for 68% of this post-hurricane mortality—apparently an isolated case.

Mortality of shorebirds after Hurricane Hugo in South Carolina was high, but this mortality did not appear to significantly reduce local shorebird populations (Marsh and Wilkinson 1991). Although post-Andrew wading bird surveys suggest no immediate impacts, we require follow-up surveys to evaluate delayed responses in foraging distribution and population levels, especially when considering damage to rookery sites and potential changes in post-storm prey populations.

Bald eagle (*Haliaeetus leucocephalus*) populations and breeding success are closely monitored. Based on pre-storm surveys, it is estimated that 10–12 nest sites, almost exclusively in black and white mangrove trees, were in the storm path. Poststorm surveys through the hurricane path found no standing bald eagle nests. Nests in Florida Bay, outside the storm path, did not appear affected. Although nest sites were lost, Andrew did not affect nesting success, though a severe winter storm in March 1993 did.[3] Similarly, Cely (1991) reported that Hurricane Hugo destroyed 44% of South Carolina's bald eagle nests, but despite the dramatic loss of suitable nesting sites, eagles rebuilt nests.

The Cape Sable seaside sparrow (*Ammodramus maritimus*) is an endangered species typical of short-hydroperiod marsh birds. Analyses of counts[4] in the summer of 1993 suggest that the storm caused a population reduction of approximately one third (from a total of approximately 6000); birds outside the storm's eye were not affected.[5]

**Table 3.** Wading bird population estimates before (3 August 1992) and after (8 September 1992) Hurricane Andrew in the southern Everglades. These data were collected by systematic aerial surveys with cooperation from the South Florida Water Management District, the Florida Game and Freshwater Fish Commission, and the National Park Service.

| Species or group | Prehurricane population (% of total) | Posthurricane population (% of total) |
|---|---|---|
| White ibis | 10,287 (49.5) | 12,865 (50.7) |
| White egret | 6680 (32.1) | 8752 (34.5) |
| Small white herons | 2000 (9.6) | 1666 (6.6) |
| Small dark herons | 1093 (9.3) | 1200 (4.7) |
| Roseate spoonbill | 300 (1.4) | 673 (2.7) |
| Great blue heron | 260 (1.3) | 47 (0.2) |
| Great white heron | 173 (0.8) | 153 (0.6) |
| Total | 20,793 (100) | 25,356 (100) |

## Research needs in disturbance dynamics

Immediate effects of Hurricane Andrew on the freshwater environment of the Everglades ecosystem included a depletion of the periphyton mat, which is important to aquatic community structure; the change led to altered habitat use by fish and macroinvertebrates. The storm reduced the reproductive success of American alligator and damaged wading-bird roost and rookery sites. Water quality, so important to defining the unique ecological composition of the Everglades landscape, appeared little affected.

Although these short-term responses are informative, it is imperative to track the longer-term response of the system to this natural disturbance. Freshwater resources of the Everglades have evolved under a regime of hurricane events, but today the system must respond and recover under a chronic regime of external stress—altered hydrology, elevated nutrient levels, fragmented habitats, and nonnative species, among others.

Given these intrusions, can resilience be effectively maintained, thus enabling the processes and ecosystem-level interactions to recover? Ecosystems disturbed beyond the limits of resilience may recover to a system characterized by altered species composition or, perhaps, different trophic dynamics (Denslow 1985, Holling 1973). Scientists and managers must carefully design and implement long-term research and monitoring to evaluate ecosystem responses to chronic human-induced stress, as well as episodic events, such as hurricanes, fire, drought, and freezing.

Particularly relevant are trophic studies that quantify energy flows and document feeding strategies and habitat requirements of prominent pathways and species. For instance, understanding the role of pulsed organic inputs (e.g., wrack deposits and leaves) on the structure and function of detritus-based food webs would be instructive. Field experimental manipulations should quantify the effects of periphyton mat disturbance on grazing food webs, with a particular focus on secondary production of fishes and macroinvertebrates. Higher trophic-level consumers, such as wading birds and alligators, are expected to be especially responsive to disturbance of trophic-level processes at lower levels, and, thus, we should monitor population dynamics and document linkages to low trophic levels.

Ultimately, these empirical field studies should be applied toward development of ecosystem, as well as species-specific or community-level models, enabling scientists and resource managers to predict and understand the role of hurricanes and other disturbances in shaping the Everglades freshwater environment. In response to such questions and data needs, the National Park Service has launched a new research initiative to acquire a greater understanding of the long-term consequences of hurricanes on Everglades ecosystems.

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